INSTITUTE FOR SPACE STUDIES

STUDIES IN COSMIC HYDROMAGNETICS

Preliminary Report

S. R. Sreenivasan

1961

Goddard Space Flight Center

National Aeronautics and Space Administration

STUDIES IN COSMIC HYDROMAGNETICS

AN OUTLINE

OF

RESEARCH PROJECTS

S. R. SREENIVASAN

NASA GODDARD SPACE FLIGHT CENTER

INSTITUTE FOR SPACE STUDIES

NEW YORK 27, N. Y.

1961

CONTENTS

1. INTRODUCTION

A general programme of investigations in Cosmic Hydromagnetics is outlined. These researches were initiated in Washington, D. C., in 1961 March at the National Aeronautics and Space Administration's theoretical division, under a fellowship awarded by the U. S. National Academy of Sciences. The general scheme of the investigation will be followed subject to variations in content as well as manner of investigation, suggested from time to time as the project evolves.

As and when a certain material reaches some degree of clarity of presentation, we shall write technical reports on topics under investigation. Similarly, as and when the technical reports reach a certain degree of maturity, we shall publish them in scientific journals. After a while it is intended to present the complete material and any other pertinent investigations in the field by other authors as a coherent monograph entitled "Cosmic Hydromagnetics."

At the time of writing this report, three papers will soon get ready for publication, and seven reports which have thus far been written will become available for limited circulation.

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2. THE PROJECTS

There are four projects which constitute our general programme for Cosmic Hydromagnetics. They are as follows:

(a) Interplanetary Hydromagnetics

(b) Hydromagnetics of the Sun and the Stars

(c) Interstellar Hydromagnetics

(d) Galactic Hydromagnetics

We follow this order because, as we go from (a) to (d), the 'characteristic length' of the system under consideration increases, and this would indeed be the order in which we see the events if we travelled across the galaxy from the earth.

3. We shall now attach the technical reports and the materials intended for publication. As and when future reports are issued, they can be added to the files.

1961 December. S. R. Sreenivasan

INTERPLANETARY HYDROMAGNETICS

We shall present a very brief summary of what has been done in the field, what remains to be done and what could be done. It is the author's belief that all the physical phenomena one observes in Interplanetary space, literally between the surface of the earth (excluding the unionized column of its atmosphere) and the photosphere of the sun, should be explained clearly as a continuous sequence of events, qualitatively as well as quantitatively by physical theories which are smoothly matched to one another. Basically a solar gas reaches out to the earth and an albedo gas reaches out of the earth, and all the physical phenomena we observe (listed on page 1-2 take place as a result of these gas streams and their interaction with magnetic fields associated with the sun, the earth and the space that intervenes. There are quite a few theories in the market, some contradict each other, some agree with each other and some more will arrive on the scene. There is enough scope for improving the situation and plenty of bold speculation, strong reasoning, skillful mathematics and sound physics are needed to draw out of this competition a clean theory of Interplanetary Hydromagnetics. It is premature to predict how much could be done but an attempt should be made.

SOLAR HYDROMAGNETICS

Whether the sun possesses a general magnetic field or not has been a long debate among the great masters of solar physics. But it seems

likely that the sun does possess a general field (see our note no. 4) and that this is related in a curious way to the sunspot fields. There are arguments for and against the possibility of detecting a general field by Zeeman-spliting measurements. The most accepted theory of sunspots and solar flares has not yet arrived. The coronal features strongly indicate a field pattern and the subject of granulation in the solar surface and associated convective motions are an exciting topic for study.

Solar Hydromagnetics is a tough field as Cowling remarks but tough fields are the most challenging pieces for research and if some progress could be made toward a unified approach, the results could be exhilarating.

COSMIC HYDROMAGNETICS

The contraction of a gas cloud in the heavens to yield the twinkling stars one sees during night is still an unsolved problem in spite of the monumental contributions by Jeans, McCrea, Mestel and Spitzer and others. And so is the systematic theory of formation of galaxies. A browsing through any of the IAU-IUTAM Symposia on Cosmical gas dynamics will reveal the many storehouses of accurate and complete theory that are still open. The origin of cosmic rays has baffled many a bright mind since Millikan speculated them to be energetic electrons. The clue to the origin of this radiation is lurking somewhere in this domain and a good search is worth the while.

The varied pattern of nebulosities and the striking photographs of the Crab present a rare opportunity for a study of subtle magnetic movements of the interstellar gas. The concepts of turbulence and collision have been very popular in the explanation of these phenomena but a clear demarkation of the specific role and effect of these and a synthetic treatment of the several effects have not been presented yet.

It is only very true to say that these problems will long engage the minds of many people but some effort in this direction might add a little drop of water to the mighty ocean of knowledge that is yet to be amassed.

SCIENTIFIC REPORT ON COSMIC HYDROMAGNETICS

NO. 1

The Interplanetary Magnetic Field

and its

interaction with the solar plasma

part one

23 March 1961

The Interplanetary Magnetic field and its interaction with the solar plasma. by S. R. Sreenivasan

Abstract

A model of interplanetary magnetic field is proposed and its interaction with the solar plasma is envisaged to offer an explanation for the formation of Van Allen belts of radiation, the occurrence of geomagnetic storms, aurorae, air glow and the diurnal variation of cosmic radiation. A qualitative explanation is presented of these phenomena and a quantitative discussion is promised in subsequent notes.

The Interplanetary Magnetic field and its interaction with the solar plasma — Part One

1. Introduction

We will examine in this note some aspects of Interplanetary plasma dynamics and in particular the Interplanetary magnetic field and its interaction with the solar plasma. We shall also see that this leads us to an understanding of some of the Geophysical phenomena like the production of Van Allen belts, the occurrence of magnetic storms, aurorae, the air glow and the dirunal variation of cosmic ray intensity. We shall not demonstrate quantitatively all these aspects but will only sketch here the qualitative aspects. A quantitative account will, however, be presented in due course. Some of the ideas expressed here may not entirely be new and explanations unique but the foregoing ideas have been very useful in the formation of the general picture that results.

2. The general nature of the Interplanetary magnetic field.

We make certain assumptions here and we hope they are not completely unwarranted. The main assumption is that the sun and the earth both possess a general magnetic field, and that the sun streams forth plasma frequently. We do not intend to consider any mechanism of such streaming here although a certain picture will be presented in a subsequent communication which will be quite consistent with the rest of the discussion in this series. As a sequel to this communication we intend to present a note on each of these aspects:

(a) a theory of solar flares and emission of solar radiation and solar matter

(b) formation of and physical processes in the Van Allen Radiation belts outlining a solar injection mechanism

(c) Magnetic Storms and Aurorae

(d) The diurnal variation of cosmic radiation and related aspects of C Rays.

Having assumed that solar matter has got out of the sun we shall proceed to follow the material towards the earth. We shall also consider it possible that the sun emits more than one beam at a time. This solar material being ionized carries with it a "frozen-in" magnetic field. This material spreads out up to and beyond the earth's orbit. Chapman (1957) has proposed earlier an extension of the solar corona and several others including Biermann and Parker have written about solar streaming or the

solar wind. We postulate that this solar gas sets up some kind of a magnetic field as shown in the figure (see figure 1) which is roughly equivalent to placing a dipole-like field in between the sun and the earth and which does not just stay there but moves along in the sun-earth plane partaking in solar rotation according to the well known theorem of corotation proposed by Ferraro. Whereas the solar matter streams out of the sun in these beams, there should be some kind of backward-flow in between these beams (see figure 2). This interplanetary magnetic field is replenished frequently, of course, by fresh solar matter.

When matter flows in these beams it naturally drags the existing Interplanetary field with it thus elongating the magnetic lines of force. The back-flow of solar matter in between the beams with the radial flow in the beam render the field configuration a tube-like appearance which has already prompted Gold, Morrison, Cocconi and Hayakawa (1959) to name it "solar-tongues," while the apparently radial elongation of the lines of force in the beams has prompted other workers to presume the field to be radial. This Interplanetary magnetic field with the earth's permanent general field gives rise to neutral points which will act as the apex for cones of injection of solar material into the earth's vicinity and cause the great belts of trapped particles round the earth. This longitudinal injection although not being able to escape remains trapped, while fresh beams of gas replenish the belts with particles. It is to be pointed out at this stage that the

neutron-albedo-decay also contributes, to a considerable extent, to the particle population in the belts, but it seems hardly likely to explain the whole set of associated phenomena which cannot be viewed separately from the existence of these belts. One should remember that the energy content of the Van Allen belts is by itself not sufficient to account for all the geomagnetic phenomena, but it is suggested that the Van Allen belts act like a constant-level head apparatus and every time there is a fresh gush of solar stream the extra supply of solar material causes events like the magnetic storm, aurora, air glow, etc. It is also suggested that the flood of solar material sets up a ring current which produces a drop in the earth's magnetic field and as the earth gets out of this beam the earth's field is gradually restored while the sudden drop occurs very soon after the Van Allen belts have encountered a new beam.

This peculiar magnetic configuration also enables the transit of solar cosmic rays to be very swift as the feeding has to take place in the region marked in figure 3. The occurrence of aurorae can also be explained on the basis of this model. On the day side the magnetic lines of force are pushed and this results in a compression of the field lines leading to an acceleration of charged particles and the field lines are pulled out leading to a rarefaction of the field lines on the night

side guided by the magnetic lines of force and this will produce the aurorae.* The different kinds of aurorae are possibly connected with the different kinds of geometry resulting from this sudden compression on one side and the corresponding rarefaction on the other side added to the fact that the entire field configuration is rotating. This might account for the curtain-like structure of the aurorae. We propose to devote a note to the different possible structures. Finally, we wish to refer to the differential streaming in opposite directions of solar matter being responsible for a diurnal variation of Cosmic ray intensity, and the general pattern of the drift curve being responsible to the magnetic storm, aurora and air glow.

figure 4.

Max. current flows in the auroral region centered around 65° latitude.

Whereas the complete quantitative picture is to be presented in future notes, we believe that this model of interplanetary magnetic field makes such a unified discussion a little hopeful.

* ~~- add the extra material here~~

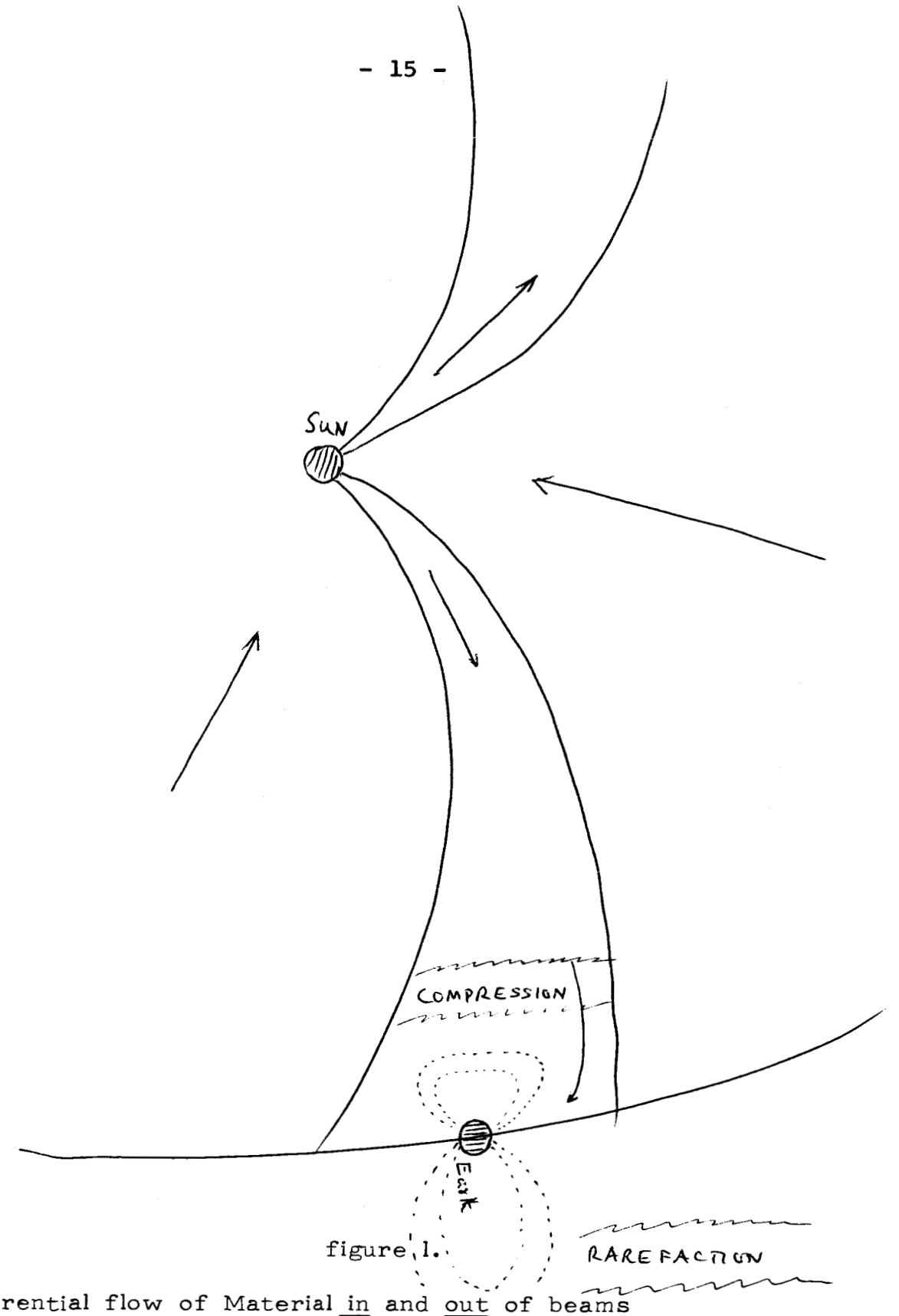


figure 1.

Differential flow of Material in and out of beams

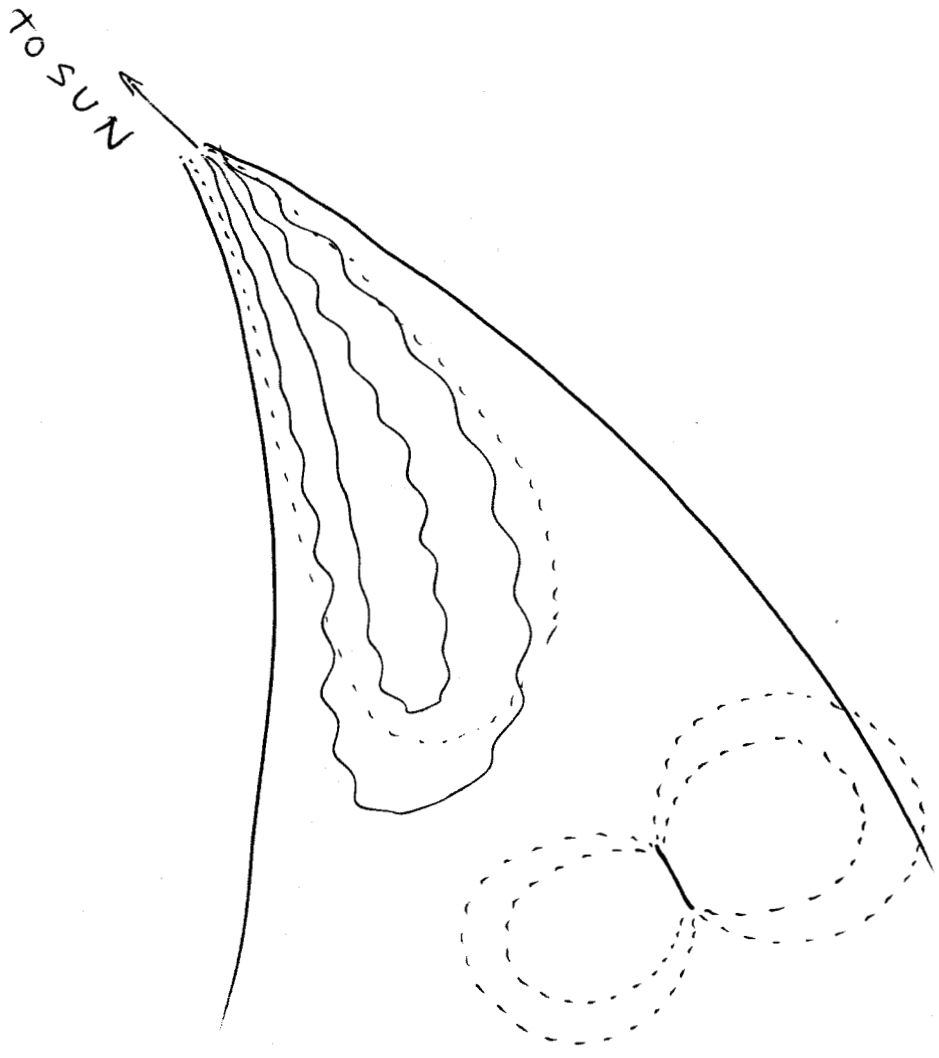
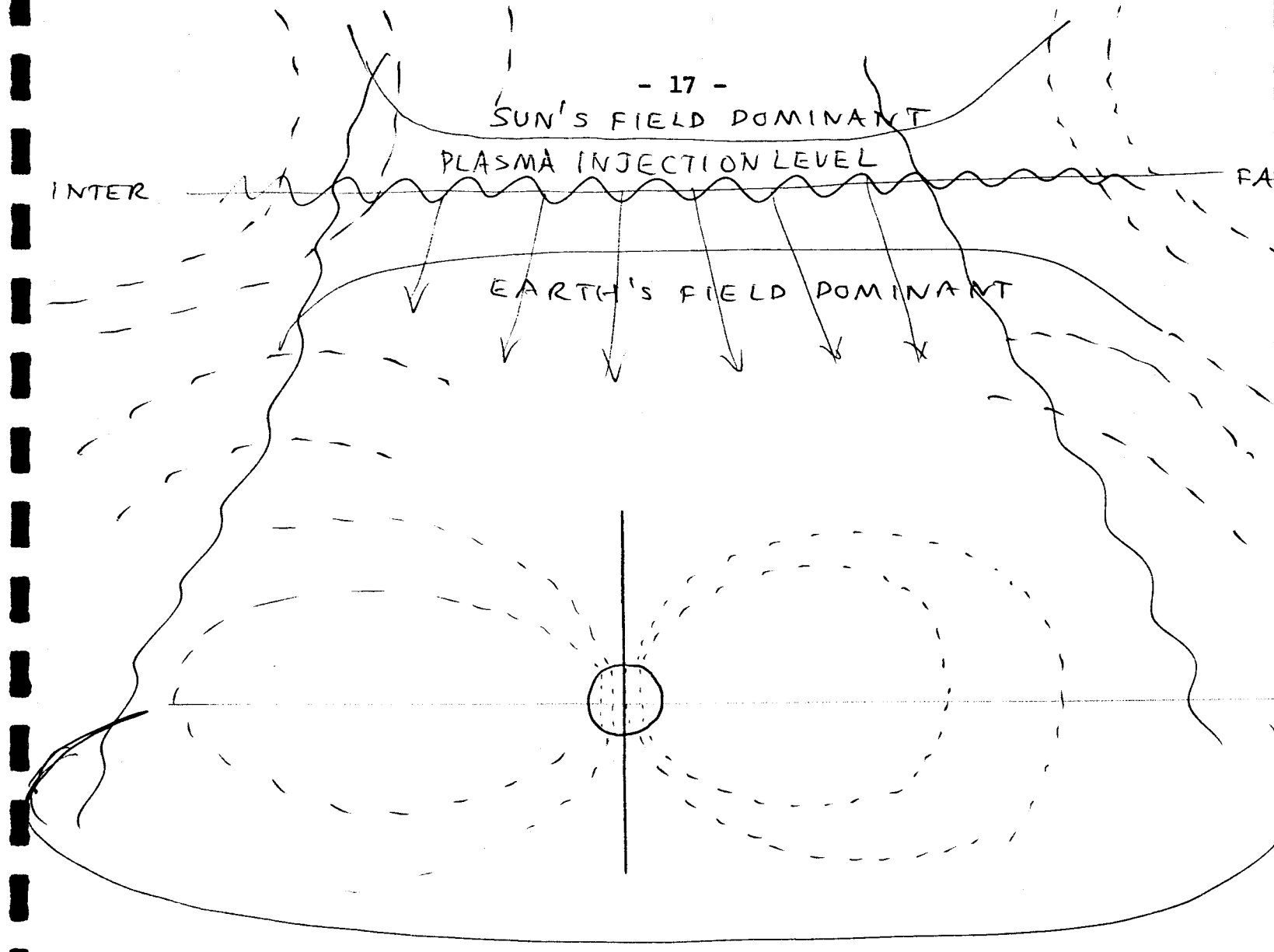


figure 2.

solid lines represent the elongations during the time when the beam is on - These when sufficiently elongated will resemble Gold's "Solar-tongues."



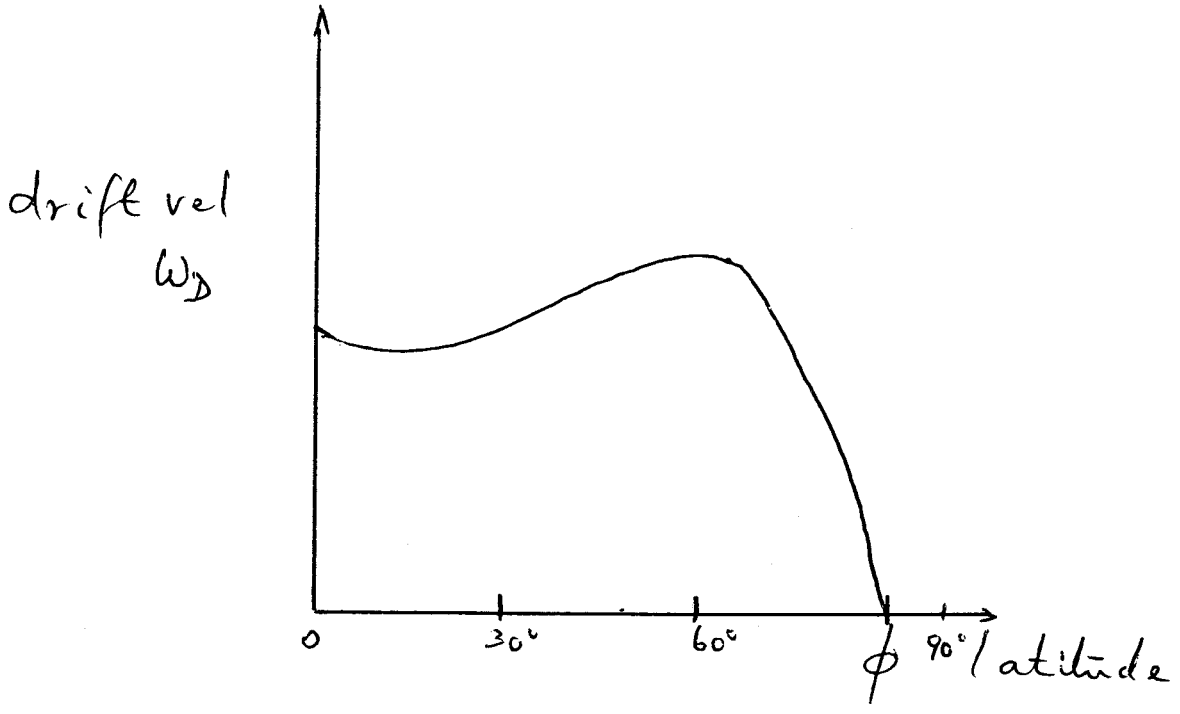
The earth being a permanent magnet has lines of force flowing in opp. direction inside the sphere.

figure 3

The Injection-Cone and the earth.

The Earth is in one of those beams - Nbte the lines of force.

Fig. 4 – indicating only the shape of the curve. peak depends on energy of particle.



If $\omega^2 = \omega_\perp^2 + \omega_\parallel^2$ for the velocity of a charged particle the drift is given by

$$\omega_D = \frac{1}{\omega_c R}\left(\tfrac{1}{2}\omega_\perp^2 + \omega_\parallel^2\right)$$ [cf (Spitzer, 1956): Physics of Fully Ionised gases

R = Radius of Curvature of line of force

$$\omega_c = \frac{ZeB}{mc}$$

B = magnetic field strength ; the other symbols have their usual meaning

SCIENTIFIC REPORT NO. 2 ON

"COSMIC HYDROMAGNETICS"

On the Formation of Galaxies

10 April 1961

A Note on the Formation of Galaxies

by S. R. Sreenivasan

Abstract

Starting with a uniform distribution of gas in the universe and the simplest kind of a permeating magnetic field the sequence of events leading to the formation of a spiral galaxy is visualized. If the physical picture presented here turns out to be meaningful it seems possible to construct a mathematical model which, together with the physical picture visualized here, might help toward an understanding of the many physical phenomena observed in and around the galaxies.

1. The Dynamics of an Ionized gas in a rotating magnetic field.

Introduction

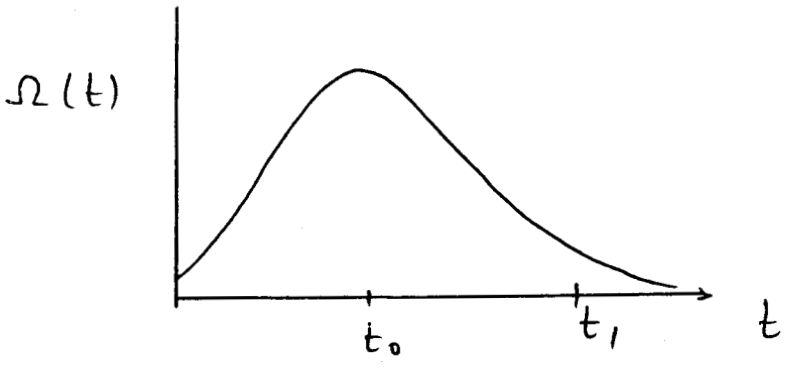
The general problem of the dynamics of an ionized gas in the field of a rotating magnet does not seem to have been thoroughly investigated. It needs no emphasis that this is the central problem both from the point of view of Hydromagnetic theory as well as of theoretical astrophysics. Simply stated, the entire universe is filled with ionized gas caught in rotating magnetic fields. Except for isolated regions like the earth's unionized atmosphere, the oceans that fill its surface and the crust that delimits the hot mantle inside the earth and the oceans and its atmosphere, the universe is all ionized or conducting matter. Although admittedly the general problem under mention is extremely complex and most certainly difficult, its solution is by far the most desirable and one of ultimate necessity.

Even if we do not finally succeed in producing Alladin's magic lamp and the gin we will certainly gain considerable insight into the physics of the cosmos and, in the least, the effort is educative.

The author has in mind the particular problem of solar matter streaming past the earth (which is a rotating magnet) and its neighbors (which plausibly also possess magnetic fields) and the associated geophysical phenomena as well as the general circulation of interstellar gas clouds which stream past stars and galaxies which are again rotating magnets. In this note we seek to visualize the formation of a galaxy (like the Andromeda for instance) and in associated notes consider the "solar terrestrial phenomena" and the dynamics of interstellar gas clouds.

2. The formation of a spiral galaxy.

Let us assume that we have in space a uniform distribution of gas (we do not need to specify its composition at this stage) and also a uniform dipole-like field permeating it. Let us also assume that for some reason this gas is rotating about some axis. We do not have to specify the characteristic lengths now. This is a second parameter which could be tailored to fit observational data at a later stage. Let us suppose that this rotation-velocity increases with time up to a certain point 'to' and then slows down for reasons which will follow.



Since there is no objection for several galaxies to form at the same epoch we shall suppose that a similar situation exists in the neighboring region. We shall require from dynamical considerations that this bulk of gas in the contiguous domain, we shall call it D-2, rotate in the opposite direction (sense). We do not require that it rotate with the same speed, since there could be a third galaxy in the process of formation in a region contiguous with these two. The only requirement is that there is no net angular momentum present as a result of formation of galaxies, or more briefly,

$$\sum_i \Omega_i = 0$$

At this stage we shall take a look at the field configuration in space (see figure 1 in page 6a). The two magnets are rotating in opposite senses. The figure is misleading on the boundary as there is a region of separation between them. (for purposes of illustration we have brought them closer). This is the situation when $t = o$. As $t > o$, $w(t)$ increases slowly with time monotonically up to $t = t_c$. The most important dynamical effect we need to mention is the stretching (lateral) of the lines of force. In other words the situation looks somewhat like that in figure 2 (see page 6b).

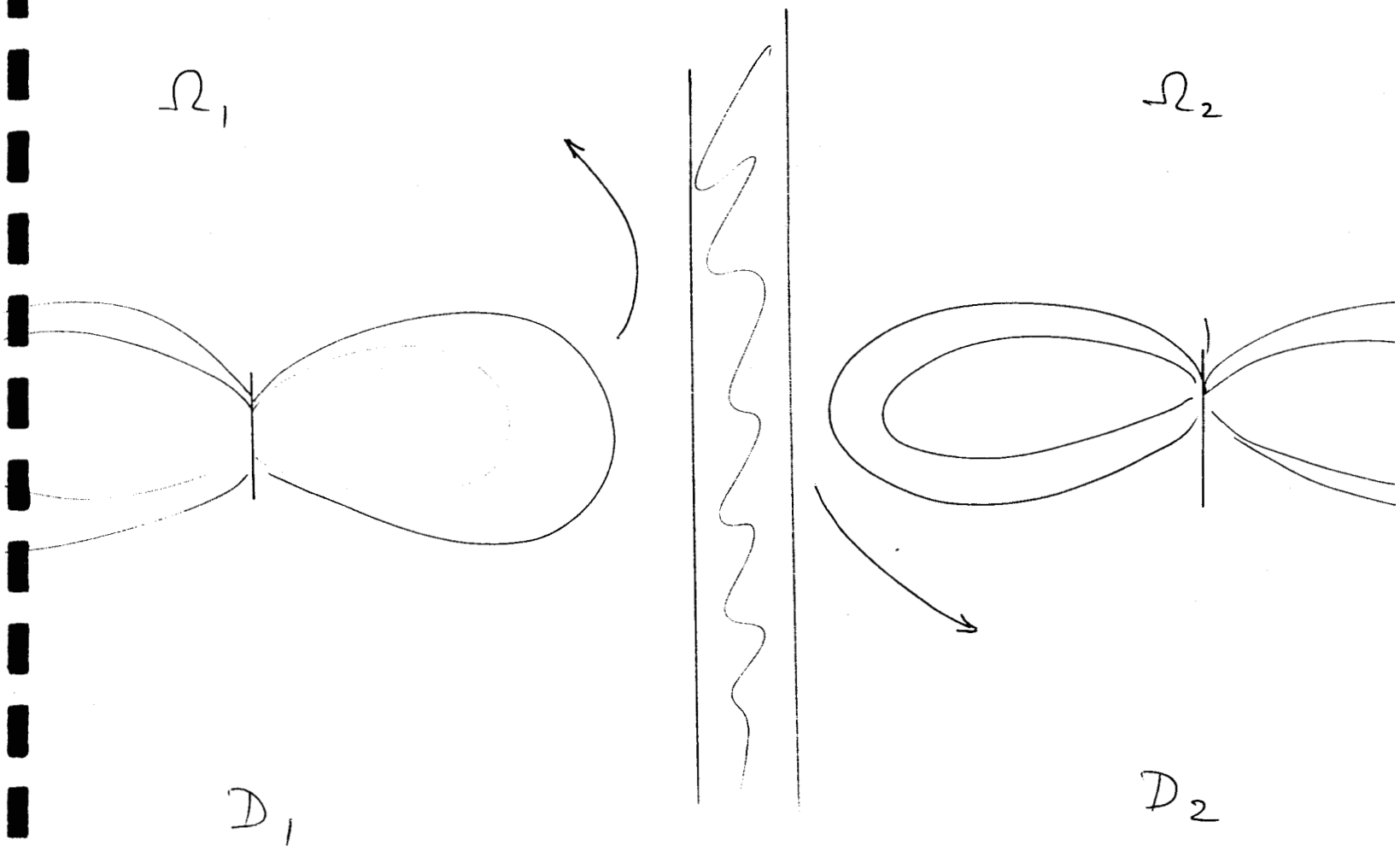


Figure 1: Two contiguous regions where prospects of formation of a galaxy exists and the initial magnetic configuration at time t = o

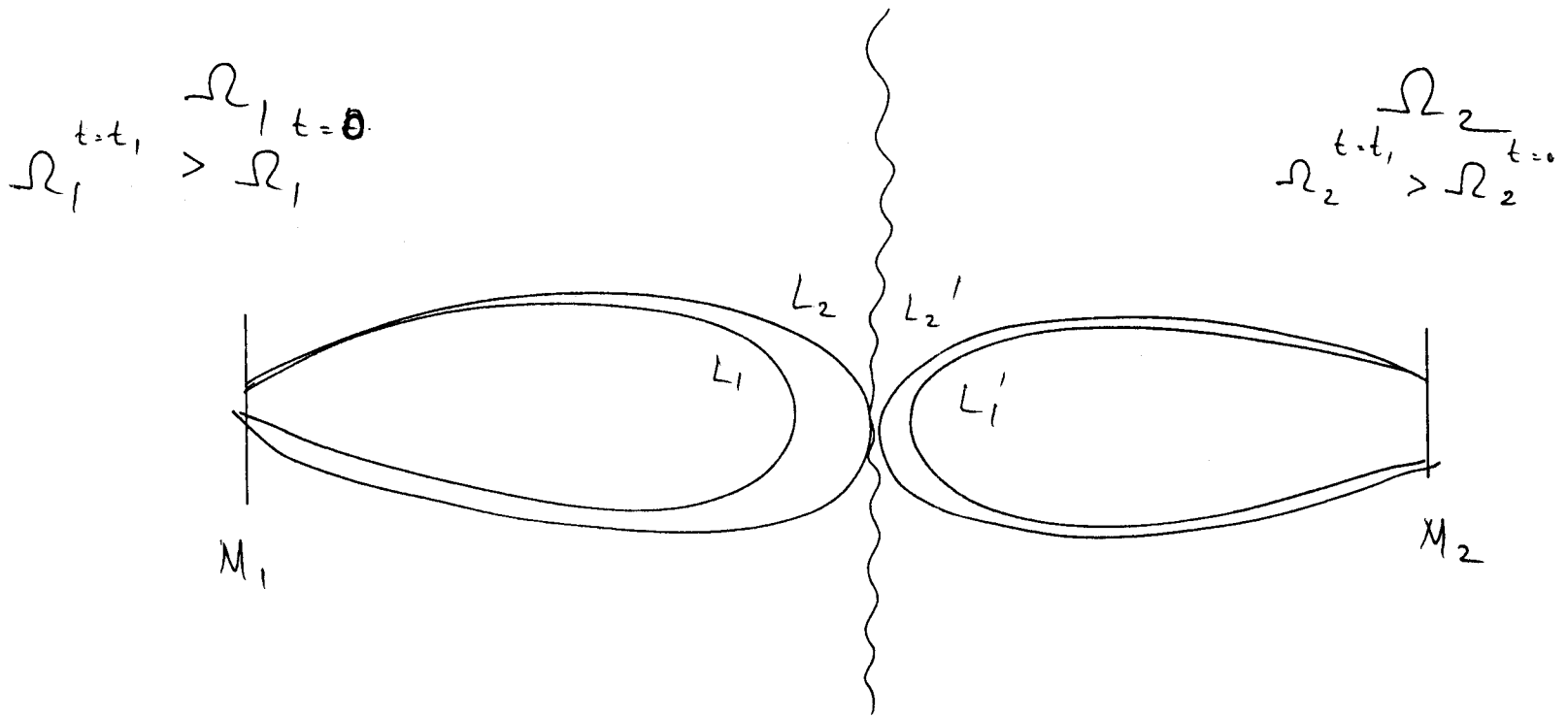


Figure 2: Lines of force stretching out when the rotation is faster. The boundary between L_2 & L_2' the outermost field lines decreasing at the same time.

As the rotation gets faster, the lines of force stretch out longer and longer until the lines of force from two contiguous proto-galaxies intersect at two points (see figure) and this should sever the lines of force. At the end of this stage we shall take a look at the density distribution of gas - momentarily, resulting in a blob of gas cloud with closed lines in the region in between the regions of rotating proto-galaxies. We use the term proto-galaxy for the entire domain in which a galaxy will eventually form. This process will, besides, fan out some gas at its boundaries. At this instance, the situation so far as density variation is concerned will be like this: the result of this rotation is to produce a relatively varified region in between two proto-galaxies. The next dynamical effect is a slow-down of the proto-galaxy by viscous effects, and a situation will occur when gas will be streaming around this region circumferentially at a velocity large compared to the angular velocity of the proto-galaxy and the middle blob B will be ejected out in a direction parallel to the stronger component of the couple acting on it as a shear.

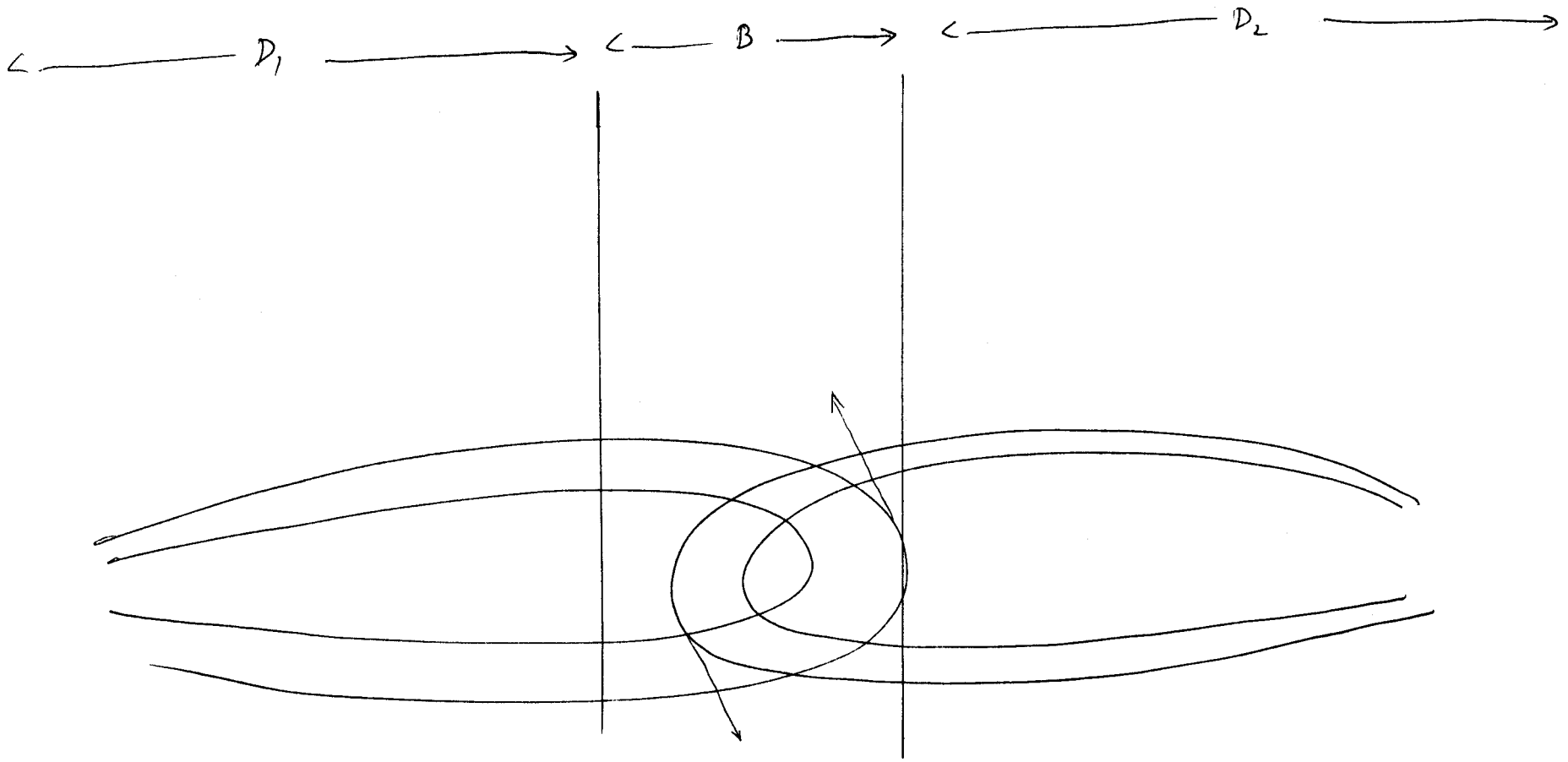


Figure 3. Two streams of gas interpenetrate each other in region B in projection

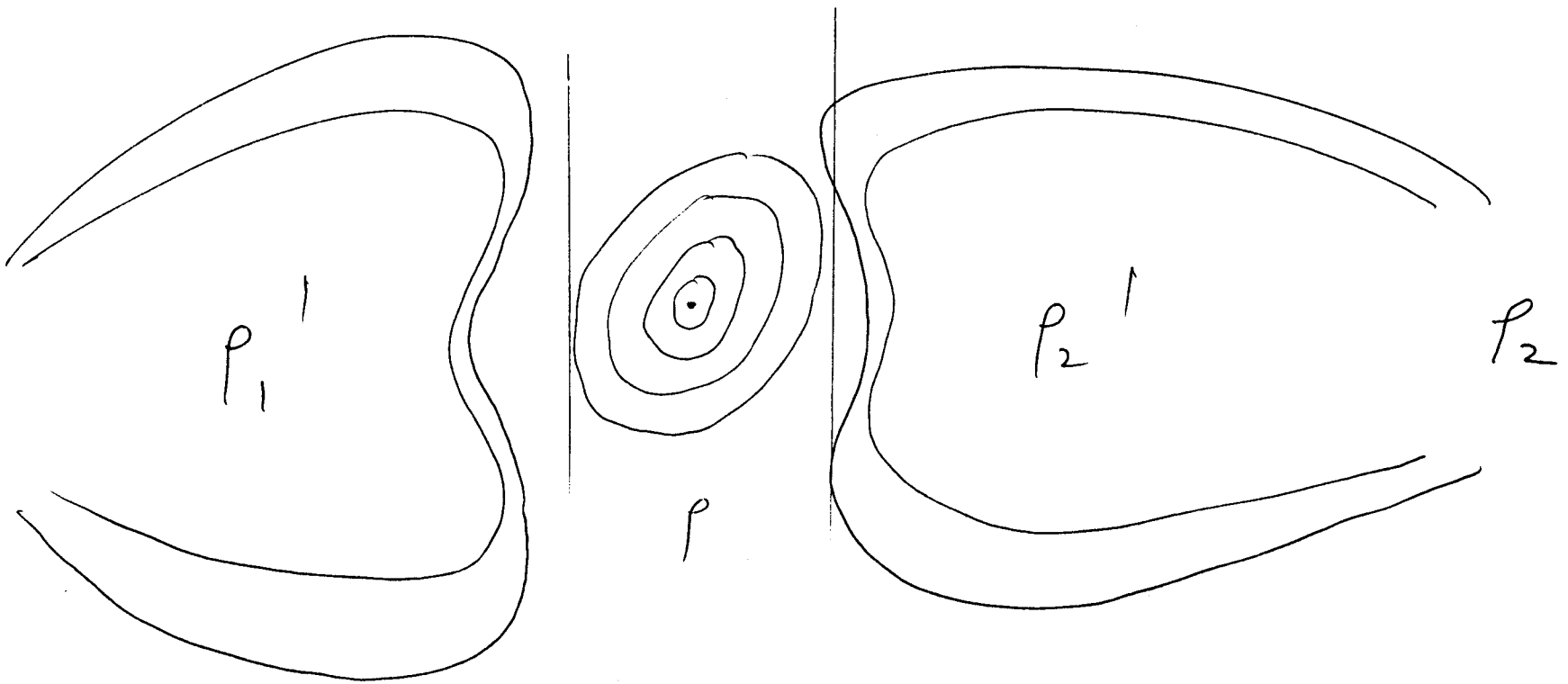


Figure 4: density-variations in the three regions

$$\rho_1 > \rho_1' > \rho \quad ; \quad \rho_2 > \rho_2' > \rho$$

The density in the primed region will be less than in the unprimed

After the region B comes into being, the density in the shaded areas is high enough that gravitational condensation of stars could take place.

If some dynamical reasoning does not preclude the several loops from collapsing after a slip so that L_1 trails ahead of L_2 and in the sequence, denser material and dust collecting at the centre, we have the galaxy as in figure 5 when it has been formed, and the gas that does not fall on the rotation R_1 but moves perpendicular to it can still not escape this region and if this upward moving gas is presumed to be hotter and has a spherically symmetric distribution around the Nucleus N_1, it could be what we usually see as the halo.

It should be pointed out again that the above mentioned description is a qualitative argument obeying the conservation laws of physics. It is submitted for public criticism and if the validity of such an account is not objected it should be possible to incorporate it into a mathematical framework, step by step.

The central region B could in turn collapse gravitationally either into a star or an elliptical galaxy or even a cluster if it is free from dust. In any case it will be comparatively a structureless mass of gas.

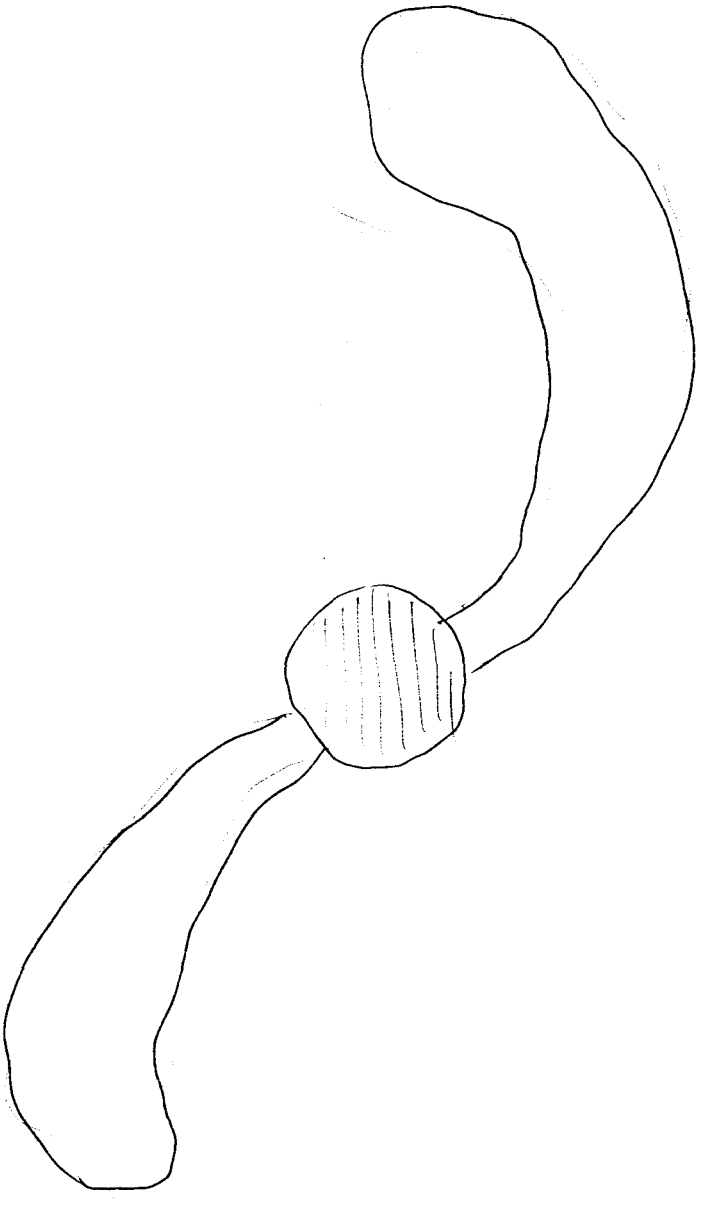


Figure 5: Final structure of the galaxy

(What has become of its other field lines? - The above picture is a density-representation. There could be field lines in space between the spiral arms.)

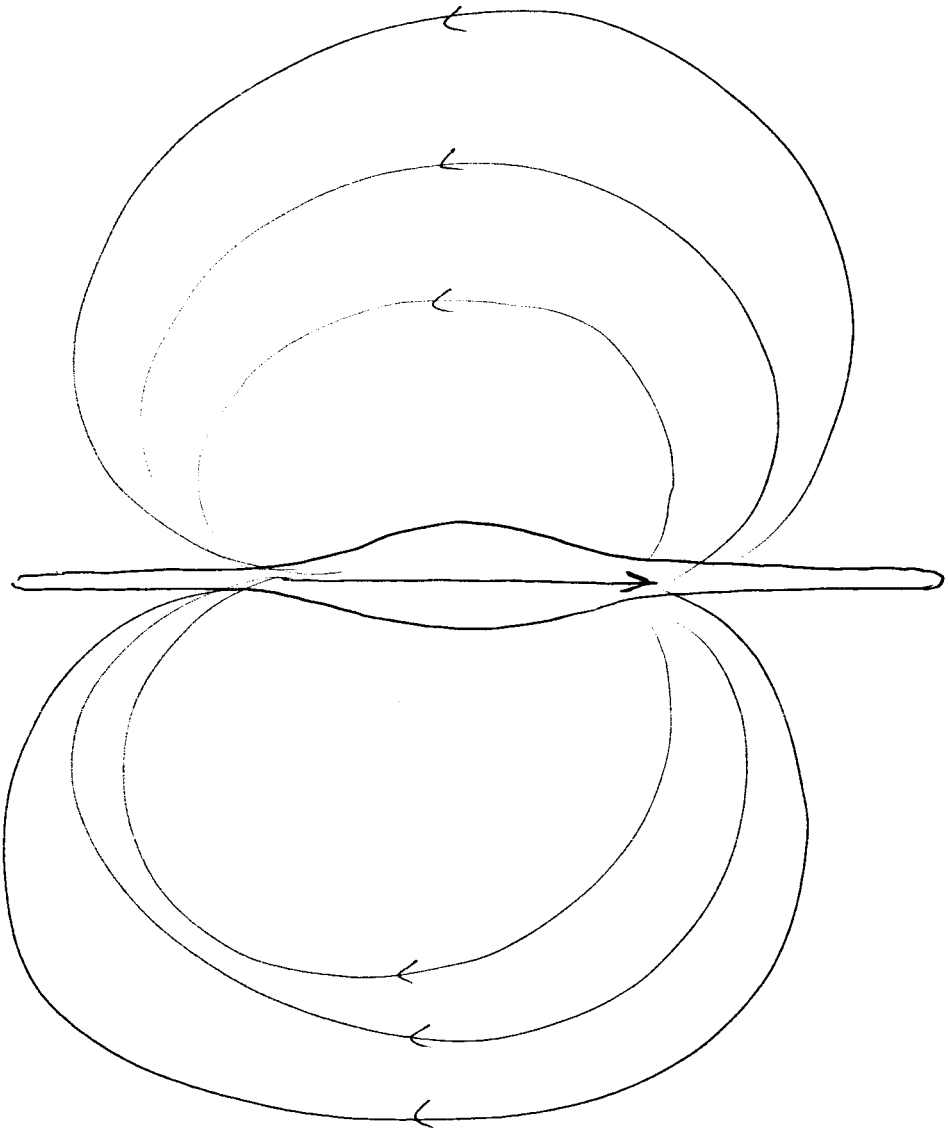
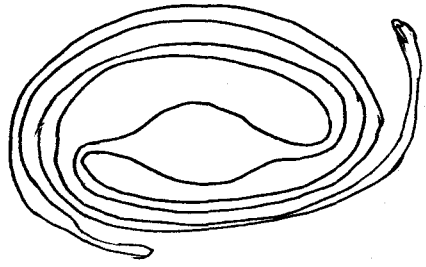


Figure 6: The Galactic Halo and the galaxy viewed edge-on with its field configuration.

Conclusions

This picture presents a field directed along the spiral arms and ties up the galactic halo magnetically with the rest of the galaxy. It also enables a maintenance of gas circulation in the galaxy between the halo and the nucleus and spiral arms. It gives us an explanation for the concentration of dust and heavy matter in the central portion of the galaxy. A magnetic field pointing not upwards or downward but normal to rotation of the axis of galaxy and the magnetic link with the halo and the associated circulation assists in the invoking of a storage mechanism for the cosmic radiation. Most of all it yields a sequential formation of the galaxy, starting with a uniform distribution of gas and a simple dipole field. Lastly it also naturally explains Fermi's moving clouds of gas with imbedded magnetic fields in the galaxy which might accelerate Cosmic Rays. These moving clouds could be the B-like regions which are dilute for a gravitational condensation to be ineffective.



If the spiral arms are squeezed into a volume whose characteristic radius is not much larger than that of the nucleus, the galaxy should have a tendency of a supernova.

Figure 8

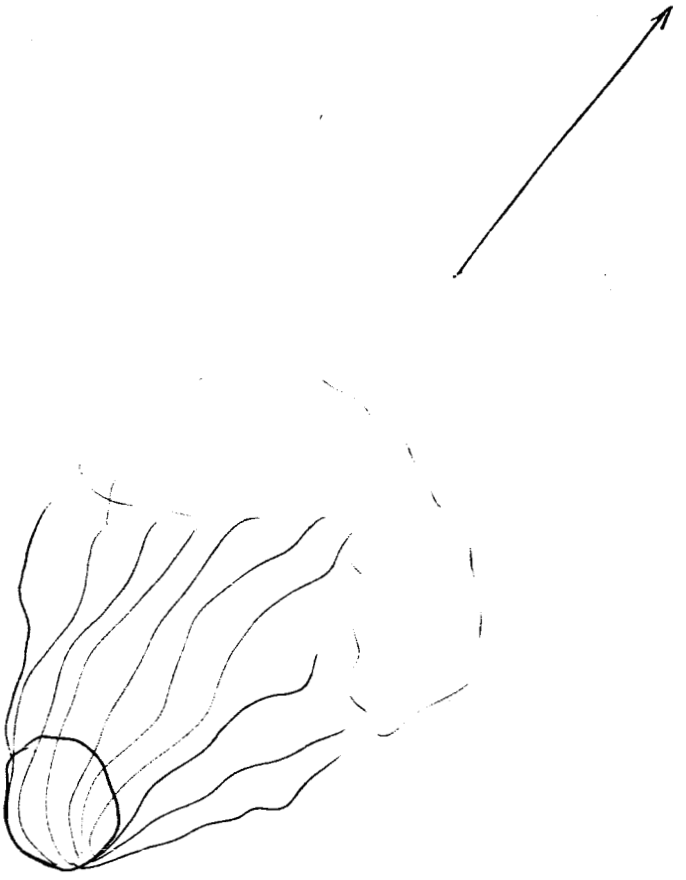


Figure 9: Supernova explosion

Compare photographs of the crab nebula

Some order of magnitude estimates:

The Sequence of galaxies:

To illustrate the point mentoned here, a series of photographs of galaxies is appended at the end. It is enough to recognize at this stage the different "Stages" of winding and the nearby mass of material (Sometimes referred to as satellite galaxy) which we identify as the matter in region B.* It does not however seem possible to decide whether the galaxy is winding up or unwinding; that seems possible only after observational evidence concerning velocities has been verified.

After this stage we shall consider a quantitative treatment of the problem. This will be treated in a separate communication.

Acknowledgement:

The author wishes to thank the National Academy of Sciences-National Research Council for the award of a Research fellowship, pursued at NASA theoretical division, during the tenure of which the research reported here was carried out.

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* See spiral Nebula M51 and the Andromeda. Look for the different stages of winding as well as different distances of the blob from the main galaxy.

He is also grateful to Dr. R. Jastrow for his hospitality at the division. The photographs reproduced here were taken from the books by Ovenden and Johnsnn. He wishes to thank Drs. J. Herring and D. Cattani for discussions.

References

1. M. Ovenden----------Looking at the Stars

2. Johnson----------

SCIENTIFIC REPORT NO. 3 ON

COSMIC HYDROMAGNETICS

A Mechanism of Solar Flares and Solar Emission

25 April 1961

1. INTRODUCTION

We require a mechanism by which the sun can be a constant source of supply of interplanetary plasma. Since we seek to explain the geophysical events purely on a solar origin, we shall outline a way of getting this plasma.

We invoke the presence of bipolar magnetic regions and require two neighboring BMR's for a mechanism of solar streaming. We envisage the crossing of two streams of flow out of these BMR's above solar surface. The BMR's are presumed to act like hoses for driving plasma out into the solar atmosphere. These hoses are thought to exist as a result of turbulence in the spot regions. The neutral points provided by the crossing of two such hoses show the clue for the escape of solar matter out into IP space.

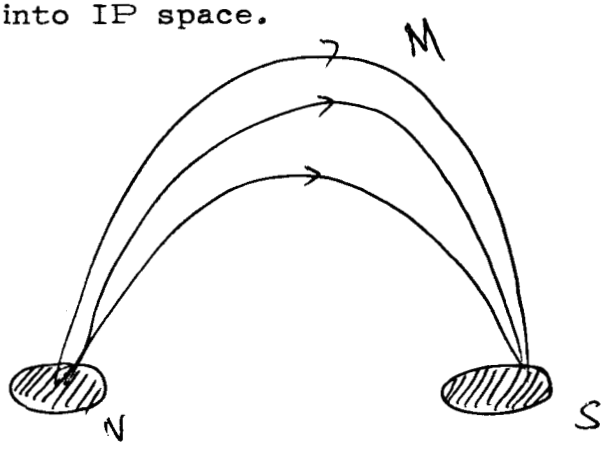

Figure 1.1 The initial bulging up of field lines and the resemblence of prominences to these field loops.

2. THE MECHANISM

The solar plasma (S-plasma) escapes out of the sun. There are magnetic fields on the sun - the local (sunspot) fields as well as the general (dipole?) field. It is not clear how the magnetic fields behave and what their precise roles are. Some kind of a severing of lines of force should take place and it is to be shown how this happens and how subsequent linkage takes place.

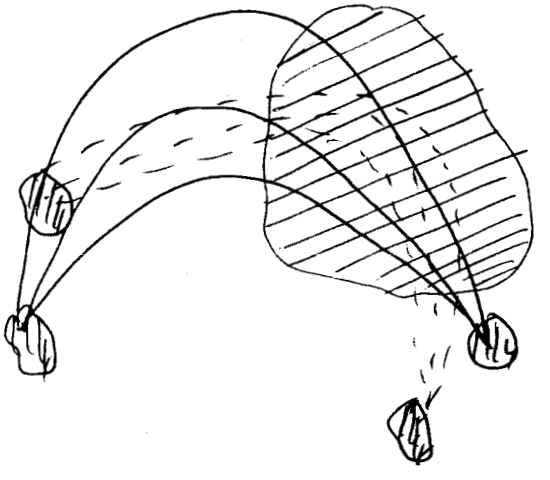

Figure 2.1 Crossing field lines of force.

In this region the gas can escape with a "field frozen in." It does not seem otherwise possible to drive the gas out. The linkage of magnetic lines of force after severing is similar to the method by which we have explained the formation of blobs of gas in our earlier paper. In such a region the flow pattern follows the magnetic lines of force.

Now the gas flows from N to S; the conductivity perpendicular to the lines of force renders the field lines to be pulled out so that they appear like inverted U's. Since $\sigma_{11} \gg \sigma_{\perp}$, we see that severing does not easily take place. We shall require that the flow velocities be very large so that N acts like a hose. The velocity in NM is greater than that in MS.

If two such hoses collide, then you have plasma agitation and optical effects could thus be expected if the velocities are very high.

Not all sunspots have the same field strength and thus not all hoses will have the same velocity of gushing and thus not all hoses show optical effects. The ones that do show will be identified as "solarflares."

We thus can invoke a mechanism common to particle emission and solar flares Only these violent gushings will give rise to flares and solar flare cosmic rays but the milder ones provide us with a perennial source for the maintenance of IP plasma.

We have thus a mechanism which permits solar emission without invoking twisting the lines of force and thus storing up energy as Gold and Hoyle (1960) require or severing lines of force. We have a common mechanism for both solar emission to maintain an IP plasma as well as for solar flares which is only the more violent of such emission. We thus associate sunspots with solar emission and provide a link with solar activity. We expect as a result that there will be no emission if there are no sunspots. This also means that we should expect a lesser number of solar flares when the sun is less active, but there could be solar streaming of particle radiation. We need to explain the inverse correlation of CR intensity with solar activity. We offer to explain this by stipulating that the sun [redacted] modulates CR intensity and acts like a scatterer. He scatters less when he is inactive than when he is active. This should however, be checked with solar physical data.

T. Gold & F. Hoyle MNRAS (1960)

3. THE OBSERVATIONAL DATA

We shall see how much the observational data are favourable for such a mechanism and shall discuss the quantitative formulation of this mechanism in Section 4. The two BMR's are initially at different latitudes, but will be presumed to be very close. Since turbulence is a common occurrence in such regions, it is possible

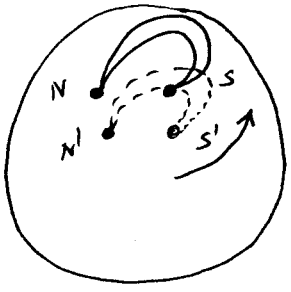

Figure 3.1 - Two BMR's, with initial field lines as drawn, on the solar disk; for the sake of illustration the BMR's are shown distinctly.

to create a situation favourable for our mechanism to operate. We have to infer therefore, that if BMR's are not close enough then the flare emission in such regions is unlikely. If they are close enough, then turbulence might bring about such a mixing process. The situation will then be in Figure 3.2.

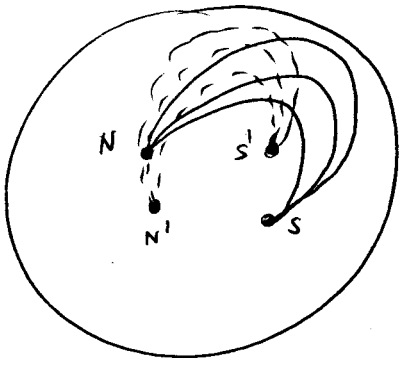

Figure 3.2 - The two BMR's with final field lines. Note that they have switched latitudes! This might be possible if they are all very close, and the region is turbulent.

At this stage, the two hoses run into each other and generate shock waves. The emission will then take place from a region which is the envelope of the neutral points. When the gas thus has escaped the field lines revert to the situation represented by Figure 3.1. Thus particle emission takes place as a result of the stampede in the sunspot traffic. A look at the diagrams appended (taken from the book edited by G.P.Kuiper (1954), The Sun, University of Chicago Press) serves to lend observational support to the theoretical argument presented in these pages. The optical effect will precede the geophysical events which the plasma will perpetrate in the earth's environment. Note the spot locations especially in diagram - (Fig. 33 in Chapter by Kiepenheuer No. 6 of book, The Sun), and also the number of field-tubes. Our Figure 2.1 represents situation in earlier diagrams.

4. ACKNOWLEDGEMENT

The work reported herein was done while the author held a Research Fellowship of the National Academy of Sciences, National Research Council at NASA, Theoretical Division. He wishes to take this opportunity to thank the Academy and Dr. R. Jastrow for their hospitality.

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SCIENTIFIC REPORT NO. 4 ON

"COSMIC HYDROMAGNETICS"

STUDIES IN HYDROMAGNETICS

Part IV A Dynamical Theory of Sunspots

12 May 1961

COUPLED MAGNETO-ELASTIC ROTATIONAL OSCILLATIONS OF A TUBE OF FORCE IN A CONDUCTING FLUID-SPHERE OR A DYNAMICAL THEORY OF SUNSPOTS

1. INTRODUCTION

This is the fourth article in Hydromagnetic theory that we wish to discuss with particular reference to the physical processes one encounters in theoretical Astrophysics, and the third in a series of studies in Solar Hydromagnetics.

When examined in conjunction with the discussion presented in the three earlier articles, a certain unity of reasoning wll become apparent. It is hoped that this linking chord will justify itself at the end. Specifically, this article should be viewed as a sequel to the third note on a theory of solar flares and solar emission, and is intended to be a discussion of the internal manifestation of the external features displayed - the magnetic morphology of the solar surface.

Turning to the problem under report, a certain variety of motions of the magnetic line of force, or more appropriately, a magnetic tube of force is discussed. The sub-title on Page 1

describes more or less what happens inside the sun. The Magnetic lines of force are endowed with an elastic property and one can thus speak of the tension of a magnetic line of force and an associated magnetic stress tensor. The rotation of the sun is supposed internally to be adopted by the lines of force. Superimposed on this rotation is an oscillation of the lines of force between two latitudes; (and in this case, 30° and 8° in either hemisphere) then follows a rotation of the U-shaped tube of force about an East-West line. This sequence of rotation and oscillation is supposed to exist inside the sun. We shall then see that this simulates quite faithfully a sunspot cycle.

2. The Observational data that is matched with this postulated rotational-oscillation is as follows:

1. In any given cycle of sunspots we observe that the sunspots are heralded usually at about 30° - 40° latitude; then they migrate to a lower latitude and this is about 8° then they disappear to reappear at the second half of the 22 year cycle at about the same higher latitude, but with opposite polarity. The corresponding sunspot groups in the southern hemisphere have opposite polarity to the northern conjugates. This is briefly the overall observational pattern that is explained dynamically by one single set of coupled oscillations.

2. The other major question that is still not settled is the fact (or fiction) of a general (dipole?) field of the sun largely noticeable in the polar regions. It turns out that it is possible to lend a dynamical model to the idea that the sun does possess a general field which is, curiously, generically related to the sunspot fields.

3. The Correspondence between the observational data in 2 and the dynamical model in 4 is the following:

1. The protrusions of the tubes of force (although we use only one of these for convenience of discussion) out of the solar surface are the observed sunspot regions which are of course connected magnetically outside the solar surface by the (invisible) lines of force. Incidentally, it should be recalled that the "lines of force" are only a picturesque abstraction. If you just pull out one of these tubes, you observe a "spot-region."

2. The ever-present rotation of the tube AOA^1 about NOS (see figures in Section 4) which is much faster than the weaker and sporadic rotation of BOB^1 about WOE gives rise to a general field of the sun. The field induced by the rotation of the line of force BOB^1 might produce a general perturbation on the P(olar)-field generated by BOB^1 which we shall call the E(quatorial)-field, and constitute a quadrupole-correction to the general field of the sun.

3d. The apparent contradictions of the predictions of this model with observational facts.

One of the contradictions that comes to the mind of the author is the existence (or do they really exist?) of Unipolar regions and he wishes to offer a 'tentative' explanation of this seeming contradiction in the argument that a Unipolar region in one area must be connected to a Unipolar region in another area in another hemisphere magnetically since unitary poles (and unitary charges?) do not exist in the universe as a whole as a consequence of the divergence relation of the magnetic field, according to Maxwell's equations.

4. The Model

Coupled Magneto-elastic rotational oscillations of a tube of force in a conducting fluid Sphere

Stage 1

The following diagram illustrates one set of rotational oscillations.

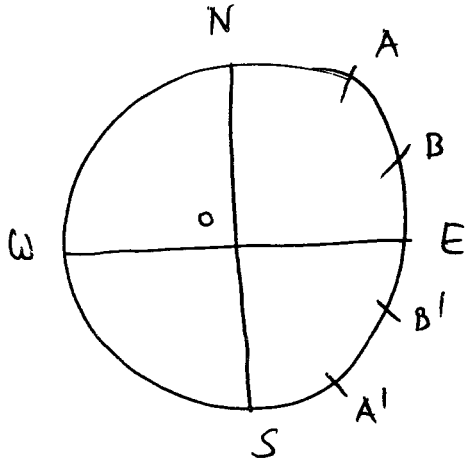


Figure 4.1

A and B are two points at 30° and 8° latitude A^1 and B^1 are the two conjugates points in the southern hemisphere.

Consider a tube of force as designated by AOA^1 and as shown in the figure.

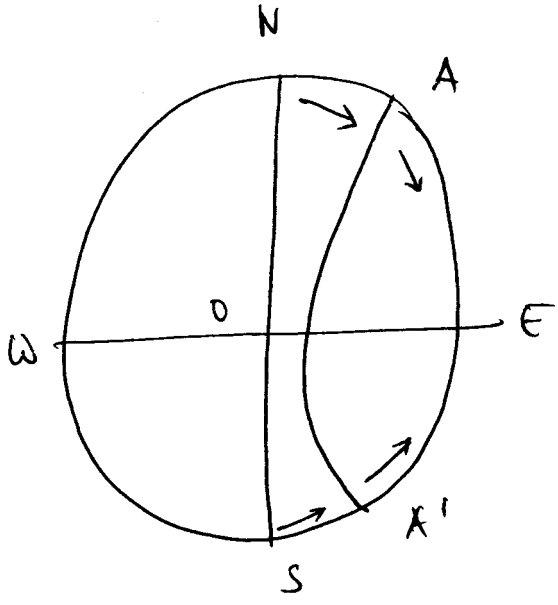


Figure 4.2

The sphere is assumed to be generally rotating about its NOS axis. Consider a mode of oscillation such as the following:

First

The tube AOA^1 is squeezed down to the position BOB^1 as follows:

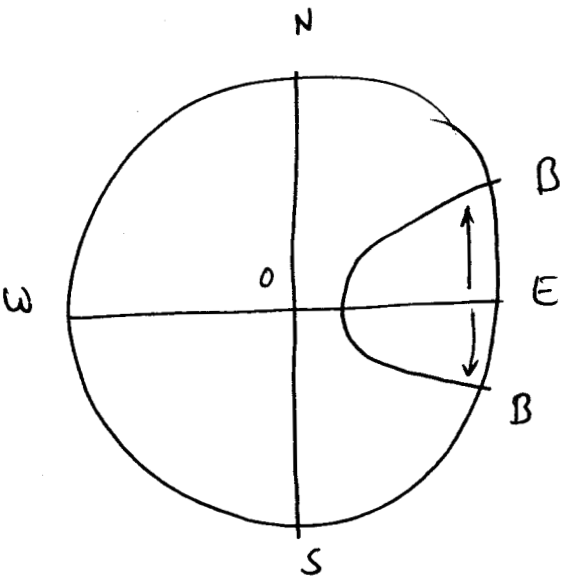


Figure 43

When the arm OA has moved to OB and likewise OA^1 moves to OB^1, the whole tube of force is rotated about WOE and the Tube assumes the new position as shown in Figure 4.4.

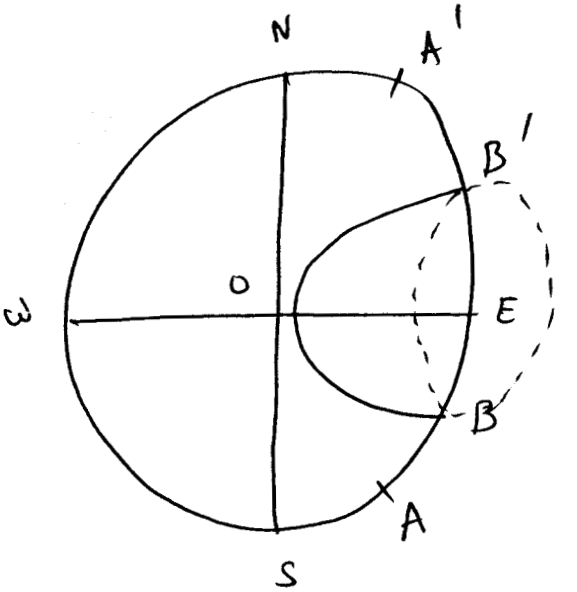


Figure 4.4

Now the tube executes the other oscillation in the reverse sense from B to A. The tube configuration is now as in Figure 5.

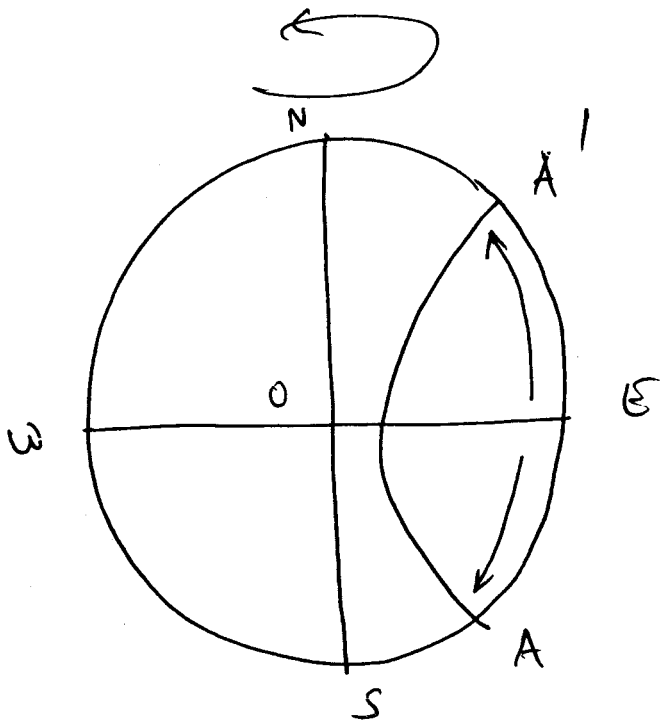


Figure 4.5

At this stage, the tube rotates about the NOS axis. Then the sequence starts again.

We shall now consider how such an oscillation could be executed by a gradient in the pressure.

The arrow inside the sphere will show the direction of falling gradient.

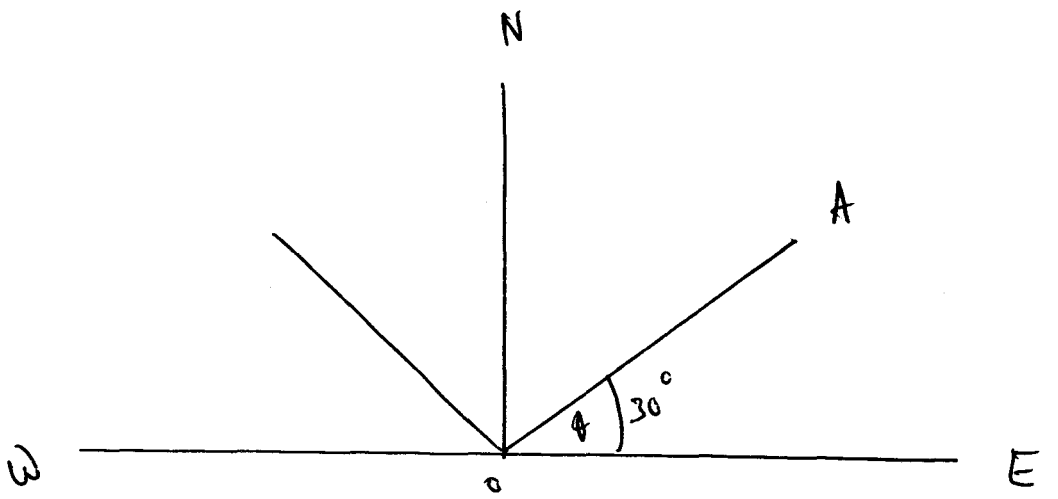


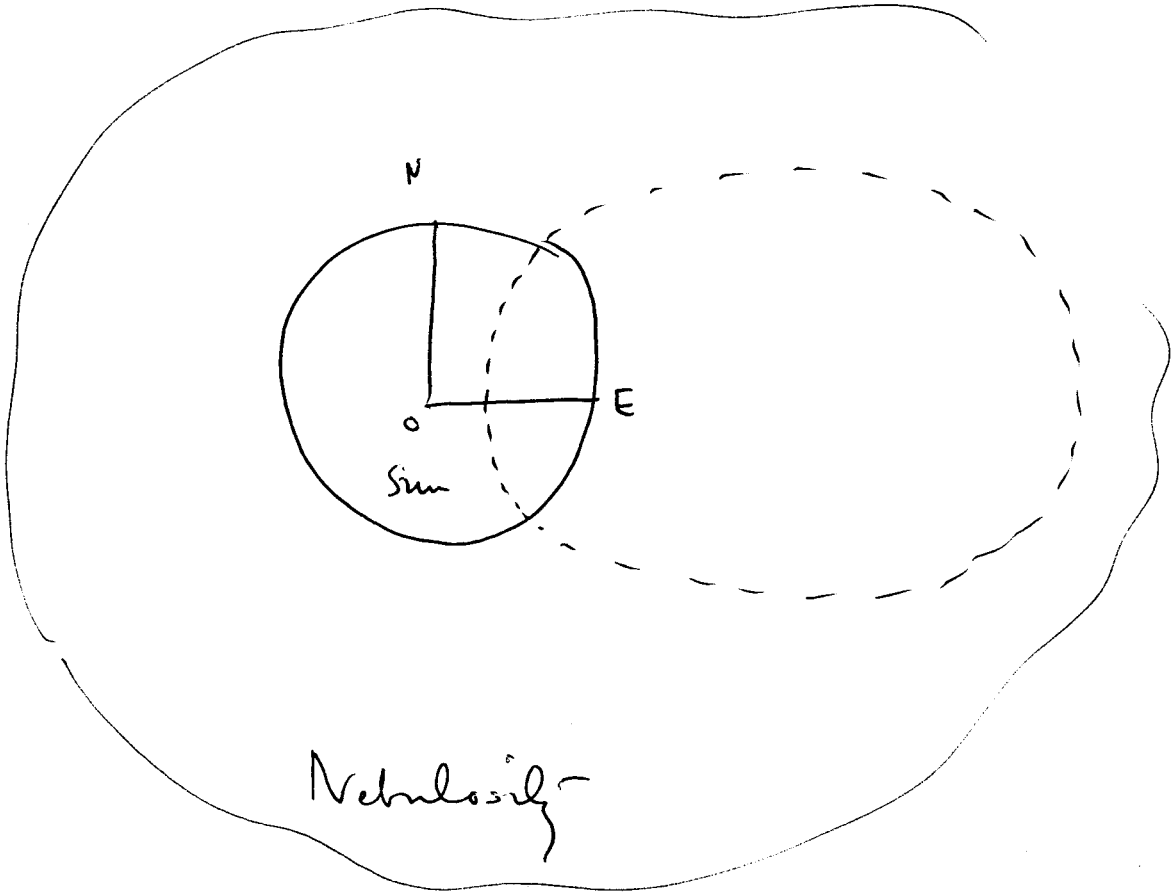
Figure 4.6

We have now replaced the tube of force by a line OA. The situation in the southern hemisphere is similar in that it is a reflection of the northern situation about the WOE axis when the line OA has moved from the position OE to OA through an angle O. It compresses the gas while it travels until it reaches a critical volume when the line OA is stopped at an angle O, and the general rotation at this point swirls the tube around once about the North-south axis, and presses the tube downward until the tube has reached the position OB, when the gas in the cone BOB' does a similar thing.

This process is now likened to a situation analogous to the sun-spot cycle. Sunspots show up at 30° latitude, travel downward until a certain latitude and then disappear, but again show up with a different polarity again at 30°. The switching of polarity is attributed to the oscillation. Note that the rotation about NOS does not change the sunspot picture.

5. The next question is

Can we describe this situation mathematically? Yes. In accordance with our practice, we shall present the Mathematical model after the physical picture has withstood some public criticism. But the one question that comes readily to one's mind when this is read will be answered here and that is - what makes the tube of force start such an oscillation? This is easy since the sun should have been formed out of a bigger nebula to which it should have been magnetically connected, and at the instant of severing the lines of force would have to be pulled either towards N or E, and in either case the oscillation advanced in this model would get going.



5. Acknowledgment

This work was done at NASA Theoretical division during the tenure of a fellowship awarded by the National Academy of Sciences-National Research Council which is gratefully acknowledged.

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SCIENTIFIC REPORT NO. 6 ON

"COSMIC HYDROMAGNETICS"

28 June 1961

A Hydromagnetic Model for the Solar Corona

ABSTRACT

A particular class of motion of magnetic lines of force were studied to explain the general magnetic field of the sun, its polarity-reversal and the sunspot cycle. These motions were inside the solar sphere. Since the sun does not have an insulating layer in its atmosphere, the motion of the lines of force inside the sphere is linked outside the solar sphere also. This is interpreted as giving rise to the shape of the corona one observes and also the variation of coronal structure with solar activity since the internal motions are presumed to be responsible for the sunspots and solar magnetic fields. The other feature of the corona that can be explained is the expansion of the solar corona due to the stretching out and seeping in of the magnetic lines of force, out of the solar sphere. This produces at the same time a fluctuating gradient in the magnetic field outside the sun and this should serve as the springboard for the acceleration of the solar plasma that streams out of the sphere.

This peculiar motion of the lines of force gives rise to a pulsation of the solar corona in interplanetary space. The effect of this on the solar streams would more nearly agree with a slower propagation than stipulated by Parker (solarwind). Chamberlain thinks a solar breeze exists. Until the complete quantitative treatment is worked out with this model it is not possible to compare this model with others.